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PROTON EVENT TIME CHARACTERISTICS AND RADIO BURST DATA.(U)

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June 1981

Final Report, for the period April 1979 to February 1981.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Various studies undertaken for relating the proton event time characteristics to radio burst data are described. Eastern hemispheric events generally have a much larger onset time compared to the Western events. For western hemispheric events, the rise time of the radio burst is found to be well correlated with the delay before onset and the time to reach the peak flux level of the protons. Directions for improvements and extensions are also discussed.

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I. INTRODUCTION

Solar flare radio spectra were shown to be predictors of significant proton events over a decade ago. The original studies[1-3] provided the basic yes-no criterion (U shaped radio spectrum). Proton event magnitudes could be predicted from various measures of the radio spectrum, based on the peak or mean flux-density and the rise time or duration of the burst.[4-6] An improved technique for the prediction of proton magnitudes has also been developed,[7-9] based on (i) using the radio burst energy as the predictive measure and (ii) applying a heliographic longitudinal correction according to the flare location. The radio energy parameter is obtained by a time integration of the radio flux at a given frequency for the duration of the U-spectrum, followed by an integration over a broad frequency range. The spectral character, or the slope, of the proton peak flux profile was shown to be predictable from certain characteristics (essentially the width) of the radio U-spectrum.[10-12]

While these studies enable one to predict the proton peak flux spectrum from real time radio burst data, they do not provide any information about the onset time for the protons or the time when the proton flux will reach the peak value, or more generally, about their over-all time development. The present project was initiated to tackle this broad area, and in particular, to determine some radio variables or characteristics that might serve as predictors of proton time characteristics. This Final Report describes the various efforts undertaken in this context.

It was recognized at the outset that proton flux data with good time resolution are essential, especially for the study of onset times. The IMP4 proton channel $29<E<94$ MeV, recorded at 10 minute intervals, provided the primary data base for this purpose. Proton data in other energy channels were also compiled, and some electron data were also recorded. The first study dealt with the effect of flare location on the onset time of the particles. As described in section II, it was found that the events originating on the eastern hemisphere had larger time intervals between the occurrence of the flare and the particle arrival time compared to those originating on the western hemisphere. However, there was no systematic locational difference in the onset time amongst the events originating on the western hemisphere. Thus the data base consisting of only the western hemispheric events would provide the proper sample for the study of correlations between radio-burst characteristics and proton flux time characteristics.

Such a study was then carried out using the rise time of the radio burst (in the frequency range 2-3 GHz or 200-600 MHz) or the rise time of the H_α flare as one of the correlation variables and the delay before onset of the protons measured from the peak (or start) of the flare or the radio burst as the other variable. Good correlations were obtained as described in detail in the Scientific Report[13], and as summarized in Section II. It was also shown in that report that the delay before onset of the protons was very well correlated with the delay before reaching the proton peak flux and also that the latter time interval was reasonably well correlated with the radio or flare rise time. These were the primary results obtained in this program. Numerous secondary studies were carried out to understand the remaining "spread" around the best fit line in terms of other parameters, but no definitive trends were found.

The main conclusions and directions for future work are discussed in section III.

II. RESEARCH WORK

A. Data Base.

The primary data base consisted of the 10 minute interval proton flux data in the 29<E<94 MeV proton channel, made available by Smart and Shea in digitized and semigraphical computer print outs. Typical background levels were 0.02 unit, (unit ≡ protons cm^{-2} sec^{-1} $ster^{-1}$). The actual onset time could generally be determined to within $\pm$ 5 minutes. The delay before onset T_1 is defined as the time interval between the peak of the radio burst (or H_α flare) and the mid-point of the ten minute time interval during which the proton flux rises decisively above the upper range of the background fluctuations. A related quantity, delay before onset T_{1S}, is defined as the time interval between the start of the radio burst (or H_α flare) and the mid-point of the ten minute time interval corresponding to the onset. Similar definitions can be given for the time to reach the proton peak flux level; T_M if measured from the peak and T_{MS} if measured from the start of the radio burst (or H_α flare).

All the events of interest were depicted graphically at hourly and 10 minute intervals. The peak levels ranged from 0.1 to several hundred units. Many events had multiple peaks and it was not possible to define the onset time unambiguously for some of them. The main advantages of this channel were high time resolution and lack of electron contamination. The main limitation was the rather restricted time range (1967 to early 1969) over which the data were available.

We also compiled a larger data base (1967 to 1973) using other proton channels (>10, >30, >60 MeV) and electron channels (>40 KeV, >2.7 MeV etc.) from the computer generated comprehensive catalog of particle events prepared by Smart and Shea. Actual onset time, peak time and total duration in each channel are available in this catalog. However, the uncertainty in these times is much greater than the $\pm$ 5 minute accuracy of the directly read data in the 29<E<94 MeV channel.

The radio and flare data were generally taken from the Simon and Svestka[14] catalog. Other sources[15-17] were used when a detailed time history or other information was available for some of the events. The rise time ρ is defined as the time interval between the start and the peak of the radio-burst (or the H_α flare).

B. Effect of Flare Location.

Each hemisphere was divided into 30^o zones and the number of events in each zone, n, and the corresponding average delay before particle onset in hours, T_1, were tabulated for each of the years 1967, 1968 and 1969, based on the comprehensive data of the Simon and Svestka[14] catalog. The results based on all events, with various degrees of reliability in terms of the flare-particle association are displayed in Table I. If we restrict the data to events with a strong flare-particle association, denoted by a solid circle in the Simon-Svestka catalog, we obtain Table II and Figure 1. It is clear that (a) East zone events have a larger delay time and (b) there is not much difference amongst the three Western zones -- the individual scatter of events is greater than the differences between their average delay times. This suggests that all West zone events can be treated as a group to study what other parameters are correlated with the individual delay times. It should be noted that in this part of the study the particle onset was not defined in terms of a particular proton channel, it simply refers to the time of arrival of the earliest particles. We also note that the results obtained here are in broad agreement with the study of Reinhard and Wibberenz[18].

TABLE I

Zone	1967 n	1967 T_1	1968 n	1968 T_1	1969 n	1969 T_1
E 90-60	2	5.0	3	5.84	2	8.75
E 60-30	2	1.0	10	2.75	2	3.25
E 30 0	3	1.0	8	3.06	5	4.30
W 0-30	8	.74	9	.92	5	.41
W 30-60	11	.54	10	.70	8	.45
W 60-90	16	.60	10	.65	13	.44
Total	42		50		35	

TABLE II

Zone	1967 n	1967 T_1	1968 n	1968 T_1	1969 n	1969 T_1
E 90-60	1	2.0	3	5.84	-	-
E 60-30	1	1.5	5	1.70	1	5.0
E 30-0	2	1.0	3	2.84	2	3.5
W 0-30	4	.68	6	.68	5	.41
W 30-60	3	.35	8	.56	6	.53
W 60-90	3	.58	4	.69	8	.47
Total	14		29		22	

C. Correlations: T_{1S} vs ρ, T_{MS} vs T_{1S} and T_{MS} vs ρ.

These correlation studies are the main subject of the Scientific Report[13]. For the 29<E<94 MeV data with good time resolution, the correlation coefficient for T_{1S} vs ρ was $r = 0.84$ for the H_α flare and $r = 0.79$ for the 2-3 GHz radio burst data (Fig. 2). Only 11 events were available due to the limited time span over which this channel was operative and due to our selection criteria. The results for other energy channels, but using the same events as above, were quite similar. When the data base was enlarged for the other channels by including later years, the correlation coefficient was somewhat reduced and the standard deviation somewhat increased, but the best fit straight line remained unaltered.

For T_{MS} vs T_{1S} we found $r = 0.96$ for the 11 events using the H_α start time as the reference time and $r = 0.94$ using the 2-3 GHz start time as the reference time. The results for other channels, but using the same events, ranged from $r = 0.83$ to $r = 0.89$. With the data base enlarged by including later years the correlation coefficient was reduced without much change in the best fit straight line.

For T_{MS} vs ρ we found $r = 0.75$ for the H_α rise time for a data base of 16 events in the 29<E<94 MeV channel. The larger sample results from the fact that events which were too weak tc provide a reliable onset time were quite unambiguous about the peak time. Similar results were obtained for the 2-3 GHz radio band rise time correlations. The results in other channels were not as good, due to their poorer time resolution.

D. Other Studies.

(1) The spread around the best fit line for T_{1S} vs ρ was systematically examined to see if it could be explained in terms of other parameters. It

was found to be random when tested against location (these are all western hemisphere events), against the eventual proton flux peak magnitude, against the radio spectral shape (U or non-U), against the proton spectral slope and against the width of the U. Similar remarks apply to T_{MS} vs ρ spreads as well.

(2) The peak flux level I_M and the ratio $R = I_M/B$ where B is the background level were plotted on a semilog plot vs. T_1, T_{1S}, T_M and T_{MS}, but no clear trend could be discerned.

(3) Events in the >40 KeV electron channel were examined for their onset time T_{1S} vs ρ. There were many more electron events than the proton events. If we considered all these events without regard to their peak flux strengths or their uncertainty in arrival time, the sample had almost 35 events and the correlation was of the order of $r = 0.5$. In most of these events the uncertainty of arrival time was only $\pm$ 1 or $\pm$ 2 minutes. If we eliminate the more uncertain (> $\pm$ 15 minutes) events, the correlation improves considerably. If we further eliminate the weak events (peak electron flux <100 cm^{-2} sec^{-1} $ster^{-1}$), the data base is reduced but the correlation improves significantly. Two events were rather special and there seemed to be problems of association between the flare and the electron increase. These have been excluded from the above considerations.

(4) Analyzing the proton peak flux times in terms of a two step process represented by $T_M = C_1 + C_2/V$ has been suggested by Reinhard and Wibberenz[18], where C_1 is a longitude dependent propagation time and C_2 is independent of the longitude. The second term represents the effect of velocity dispersion. If we take the C_1 and C_2 for the various western hemispheric events as given

in Reinhard's thesis[19], we can test whether C_1 and C_2 individually show any correlations with ρ. We found no significant correlations between C_1 and ρ or C_2 and ρ, even though T_M and ρ have a fairly good correlation. This suggests that the uncertainities implicit in determining C_2 (when there is not enough clear velocity dispersion) bring into question this type of separation for the Western hemispheric events.

(5) The decay time T_D, defined as the characteristic time in the exponent $\exp(-T/T_D)$ for representing the decay phase of the proton flux time profile, was noted for the events we studied. We did not find any significant correlations between T_D and ρ, T_{1S} or T_{MS}. In some events (with multiple peaks) the definition of T_D was ambiguous.

III. CONCLUDING REMARKS

The main conclusions of this program and the possible directions for future work are as follows.

1) There are good correlations between T_{1S} and ρ, excellent correlations between T_{MS} and T_{1S}, and fairly good correlations between T_{MS} and ρ. These results provide a prediction scheme for T_{1S} and T_{MS} in terms of real time radio burst data for western hemisphere events.

2) There appears to be a single characteristic time scale for each event which governs the radio rise time the proton delay before onset, the proton peak time and possibly the electron onset time as well. Apart from the "spread", one can make a universal model for the time development of the various components of the solar flare process; empirical observation of any one particular component then provides the time characteristics of the other components. In particular, the observed (real time) radio rise time can serve as the primary factor determining the characteristic time scale of a given event.

3) Improvements in correlations may result if a larger data base were available with the type of time resolution of the 29<E<94 MeV channel. Detailed radio burst time profiles at various frequencies would also be very useful in judging whether a given radio event has multiple peaks, and if so, which rise time is the appropriate one to use for the correlations. Improved correlations in turn would lead to a better prediction scheme.

4) Further work with various electron channels would be valuable in judging which channels provide high correlations with the radio or proton time scales. If significant correlations can be shown to exist, that empirical result would help guide the theoretical modelling of the flare development and the particle propagation processes.

5) A higher radio frequency band (e.g. around 9 GHz) can be used for the radio rise time instead of the 2-3 GHz used here.

6) Besides the simple rise time studied here, other radio parameters such as the radio peak flux, or time integrated flux, or time and frequency integrated flux, the width of the U, and the detailed time development of the radio spectral shape should be carefully examined for correlations with the proton time scales, or for understanding the spread around the best fit lines of the present study. Our preliminary results in this direction were negative, but a larger data base is needed to arrive at more meaningful results.

7) In conclusion, the present study provides a scheme for assessing the characteristic time scale for the evolution of the proton event. Earlier studies gave us the capability to assess <u>whether</u> a proton event will occur, <u>how strong</u> it will be and what its <u>spectral profile</u> would be like. Here we have taken the first step to assess <u>when</u> the protons will start to arrive, or reach the peak flux level. From the practical point of view, knowing the time scale of an impending event is extremely important.

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FIGURE CAPTIONS

Figure 1. Particle delay before onset vs Location of Flare

Figure 2. Delay before onset for >29 MeV protons vs Rise time in the 2-3 GHz radio frequency band.

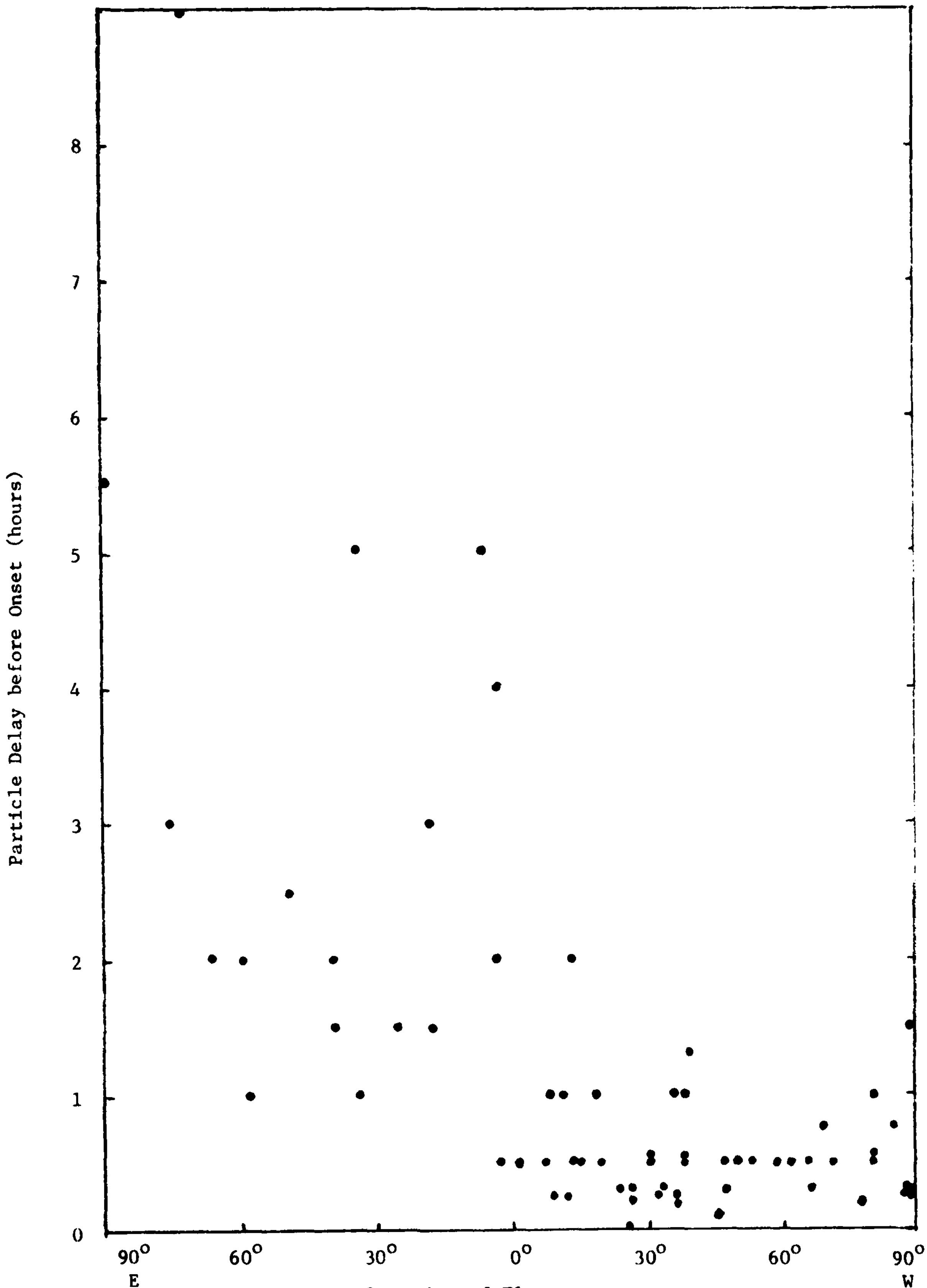
Particle Delay before Onset (hours)
0
1
2
3
4
5
6
7
8
90°
E
60°
30°
0°
30°
60°
90°
W
Location of Flare

Figure 1

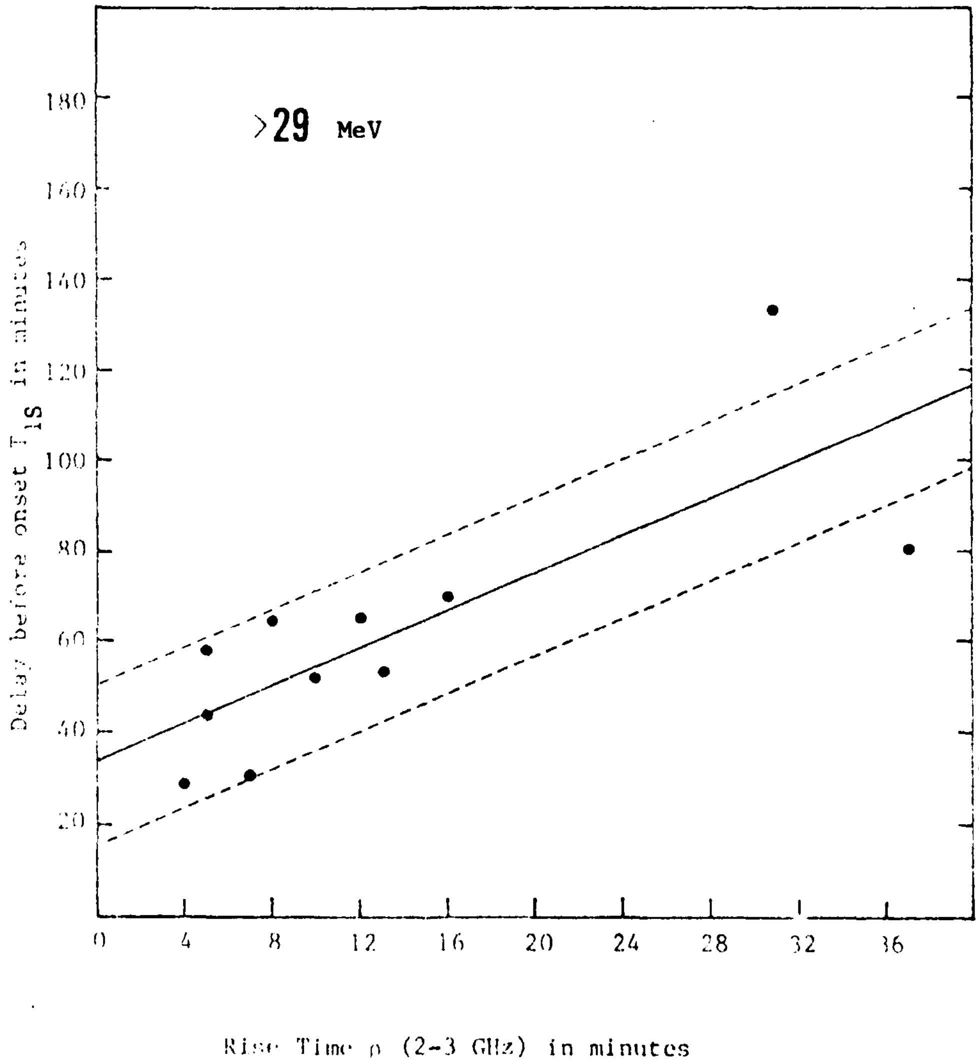
>29 MeV
Delay before onset T_{1S} in minutes
180
160
140
120
100
80
60
40
20
0
4
8
12
16
20
24
28
32
36
Rise Time ρ (2-3 GHz) in minutes

Figure 2

DAT

FILM